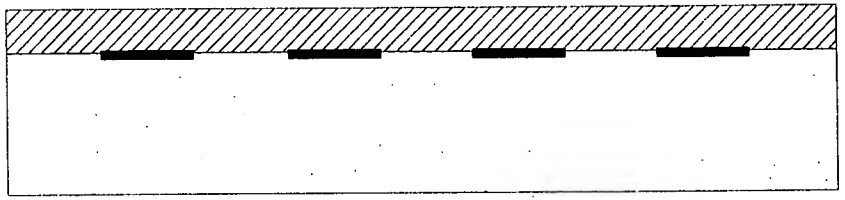
# Bi-Layer Wafer Level Underfill

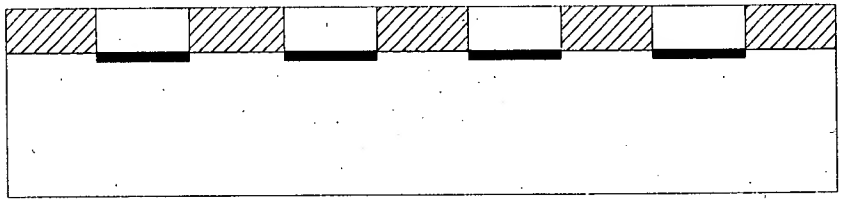
Fig 1

a) silicon wafer with BLM

b) apply first underfill layer



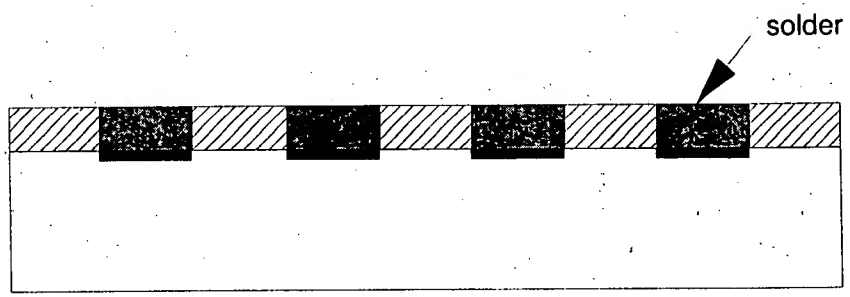
c) pattern first layer



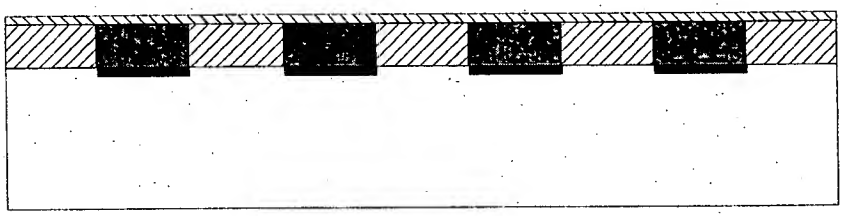
# Bi-Layer Wafer Level Underfill

Fig 2

a) apply solder in cavities

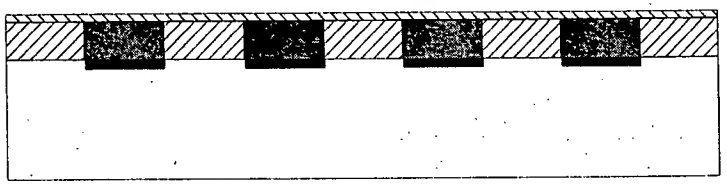



b) apply thin flux-adhesive layer

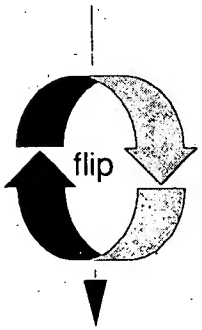


# Bi-Layer Wafer Level Underfill

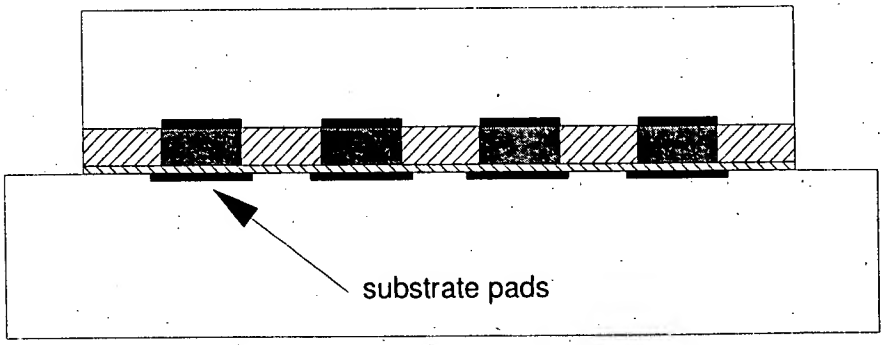
Fig 3



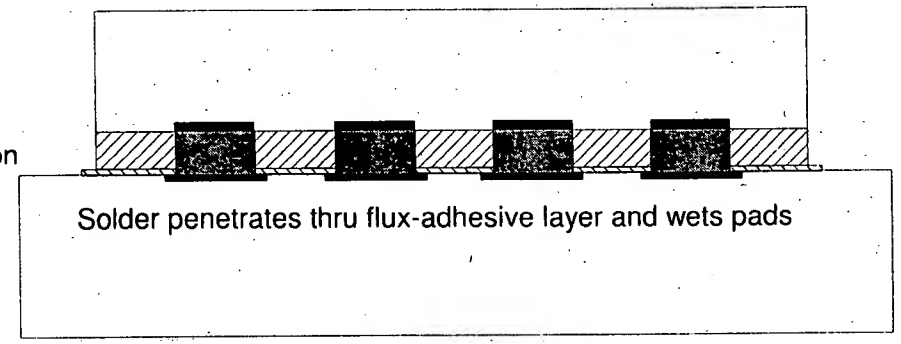
a) Diced chip with bi-layer wafer level underfill before join




b) Flip, align to substrate pads & join




c) solder reflow and flux-adhesive activation



# Bi-Layer Wafer Level Underfill

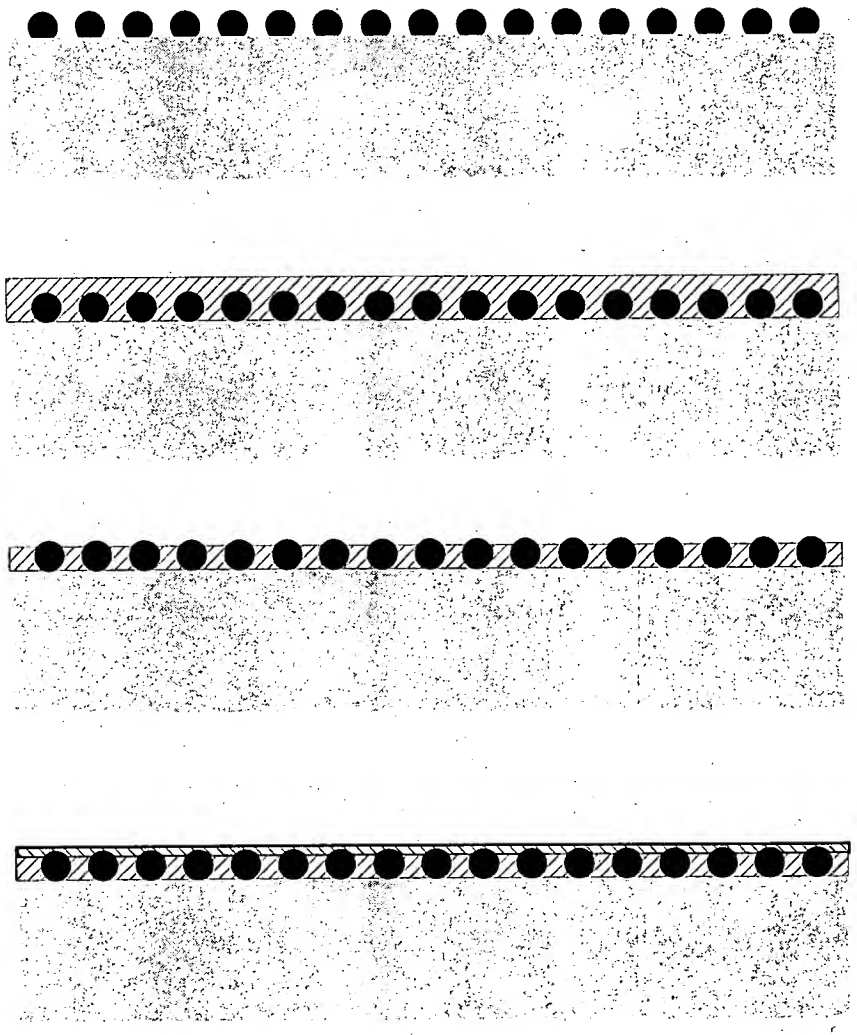
Fig 4

a) bumped silicon wafer

b) apply first underfill layer

c) polish or etch first underfill layer

d) apply thin flux-adhesive layer



- Gov't Contract

**Created By:** **Created On:**
**Last Modified By:** 1 **Last Modified On:**

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Required fields are marked with the asterisk (*) and must be filled in to complete the form .

**Summary**

| | |
|---|---|
| Status | Under Evaluation |
| Processing Location | YOR |
| Functional Area | 700 Isaac-Systems, Technology & Science |
| Attorney/Patent Professional | |
| IDT Team | |
| Submitted Date | |
| Owning Division Serial | RES |
| PVT Score Caption | 35 |
| Lab | |
| Technology Code | |

**Inventors with Lotus Notes IDs**
Inventors:

| Inventor Name > denotes primary contact | Inventor Serial | Div/Dept | Manager Serial | Manager Name |
|---|---|---|---|---|

**Inventors without Lotus Notes IDs**

**IDT Selection**

**Main Idea**

***Title of disclosure (in English)**
Bi-Layer Wafer Level Underfill

***Idea of disclosure**
1. Describe your invention, stating the problem solved (if appropriate), and indicating the advantages of

using the invention.
Flip chip technology has grown quickly in recent years as a means of decreasing the chip footprint while simultaneously increasing the number of possible I/O's. This is because it takes advantage of the chip area for I/O's instead of just the chip periphery as does wire-bonding. Various methods exist for solder bumping wafers, such as evaporation, plating, solder paste screening and more recently, injection molding solder or IMS.

Regardless of how wafers are bumped, typically they are thereafter diced into chips. For DCA or direct chip attach, these silicon chips are bonded directly to a laminate substrate. Since there is significant mismatch of CTE (coefficient of thermal expansion) between silicon and laminate materials, these chips are thereafter underfilled. This greatly increases the fatigue life of the solder bumps. However, underfilling is associated with several manufacturing problems.

- First, the process is somewhat slow. This is due to the typical dispensing method of applying the liquid underfill along at least 2 sides of the chip and letting capillary action pull the liquid completely under the chip.
- Secondly, incomplete underfills may occur. Since it is difficult to determine underfill uniformity, this could lead to excess mechanical stresses on affected bumps. This in turn leads to shortened fatigue life for the affected chip.
- Thirdly, underfilling is yet another packaging process step. Ideally, this step would be eliminated to accelerate the path from wafer to packaged chip.

2. How does the invention solve the problem or achieve an advantage,(a description of "the invention", including figures inline as appropriate)?
This invention describes a process and structure that addresses all three problems mentioned previously. In effect, a bi-layer wafer level underfill completely eliminates the separate underfilling process as practiced now. Thus, a time-consuming and somewhat problematic manufacturing step is removed. The following description with the aid of the figures serves to outline the key concepts of this invention.

As seen in Fig. 1a, a silicon wafer is at the point where solder bumps are required to prepare it for a flip-chip application. This wafer contains the appropriate BLM Ball Limiting Metallurgy covering the pads which will receive the solder. Fig. 1b shows the application of a patternable dielectric to the wafer front side containing the pads. This material may be applied by a spin coating or similar process. Unlike typical passivation layers though, this material is applied to a thickness roughly ranging between 25 and 75 microns, thicker than usual. The reason for this is its additional function as described shortly. Fig. 1c shows the dielectric layer after the patterning step. The patterning may be done by laser ablation, reactive ion or wet etching. It opens up the areas above the wafer pads.

Fig. 2a shows the key additional functionality of the thicker dielectric layer, namely as a solder mask. Solder is applied into the cavities formed after the dielectric is patterned. The method for this application is IMS Injection Molded Solder, which scans a head containing molten solder over the wafer and fills the cavities. Thereafter the wafer is cooled and the solder solidifies. In effect, this solder mask also serves as the major portion of the underfill as will be seen in the figure 3 descriptions. As seen in Fig. 2b, after the solder is applied, a very thin layer combining flux and adhesive is applied uniformly over the wafer. This again may be done with a spin coating or similar process. Once this layer has hardened, te wafer is ready to be diced into individual IC Integrated Circuit chips.

Fig. 3a shows such a diced chip containing in effect everything required to bond and underfill it to the laminate substrate. Fig. 3b shows the flipped chip being aligned and placed on the laminate substrate. Thus, the solder filled cavities align to the solder receiving pads on the substrate. The chip adheres to the laminate substrate by the step shown in Fig. 3c. Here the assembly is heated to the solder reflow temperature which serves two purposes. One, it activates the fluxing agent in the thin secondary layer thus allowing the solder to penetrate throgh it and wet (metallurgically bond) to the metallized pad on the laminate substrate. Two, it activates the adhesive in this same layer which mechanically bonds the chip to the same substrate. Since this secondary layer is very thin (typically below 12 microns) compared to the

primary layer which serves as the solder mask, there is very little solder volume needed to penetrate through it. Also, during this heating step, this layer thins still further as it bonds to the substrate. Thus most of the solder volume stays within the cavities and is surrounded by the walls of each cavity as is the case with underfill materials.

Thus, we have described a process and structure which eliminates the separate underfilling step. The details of each process step in this invention as outlined above should not be regarded as limiting, but merely as examples. To those skilled in the art, other methods may also be used to accomplish these steps without changing the novel aspects of this invention.


blwluf.PRZ

3. If the same advantage or problem has been identified by others (inside/outside IBM), how have those others solved it and does your solution differ and why is it better?
No flow underfills have more recently become popular. While they eliminate the capillary dispensing time, these must still be applied to te laminate substrate in a separate manufacturing step.

4. If the invention is implemented in a product or prototype, include technical details, purpose, disclosure details to others and the date of that implementation.
Not implemented yet.

***Critical Questions ( Questions 1 - 7 must be answered)**

| |
|---|
| ***Question 1**<br>On what date was the invention workable? **lease format the date as MM/DD/YYYY**<br>(Workable means i.e. when you know that your design will solve the problem) |

| | |
|---|---|
| ***Question 2**<br>Is there any planned or actual publication or disclosure of your invention to anyone outside IBM? | ● Yes<br>○ No |
| If yes, Enter the name of each publication or patent and the date published below.<br>Publication/Patent: None yet, but we would present it at a NIST quarterly review possibly o<br>Date Published or Issued: | |
| Are you aware of any publications, products or patents that relate to this invention? | ○ Yes<br>● No |
| If yes, Enter the name of each publication or patent and the date published below.<br>Publication/Patent:<br>Date Published or Issued: | |

| | |
|---|---|
| ***Question 3**<br>Has the subject matter of the invention or a product incorporating the invention been sold, used internally in manufacturing, announced for sale, or included in a proposal? | ○ Yes<br>● No |
| Is a sale, use in manufacturing, product announcement, or proposal planned? | ○ Yes<br>● No |
| If Yes, identify the product if known and indicate the date or planned date of sale, announcements, or proposal and to whom the sale, announcement or proposal has been or will be made.<br>Product:<br>Version/Release:<br>Code Name:<br>Date:<br>To Whom:<br>If more than one, use cut and paste and append as necessary in the field provided. | |

| *Question 5 | |
|---|---|
| Have you ever discussed your invention with others not employed at IBM? | ○ Yes<br>● No |
| If yes, identify individuals and date discussed. Fill in the text area with the following information, the names of the individuals, the employer, date discussed, under CDA, and CDA #. | |

| *Question 7 | |
|---|---|
| Was the invention made in the course of any alliance, joint development or other contract activities? | ○ Yes<br>● No<br>○ Not Sure |
| If Yes, enter the following :Name of Alliance, Contractor or Joint Developer | |
| Contract ID number | |
| Relationship contact name | |
| Relationship contact E-mail | |
| Relationship contact phone | |

**Question 9**

What type of companies do you expect to compete with inventions of this type? *Check all that apply.*

- ☒ Manufacturers of enterprise servers
- ☒ Manufacturers of entry servers
- ☒ Manufacturers of workstations
- ☒ Manufacturers of PC's
- ☒ Non-computer manufacturers
- ☐ Developers of operating systems
- ☐ Developers of networking software
- ☐ Developers of application software
- ☐ Integrated solution providers
- ☐ Service providers
- ☐ Other (Please specify below)

**Patent Value Tool (Optional - this may be used by the inventor and attorney to assist with the evalu**

(The Patent Value tool can be used by you or the evaluation team to determine the potential licensing

value of your invention.)

These are the answers which were entered into the **Patent Value Tool.**

## Market

What is the anticipated annual market size (in dollars) that will be captured by your invention?
$1B to $5B

**Question 1 -** How new is the technical field?
Emerging
**Question 2 -** How central is the invention to the product(s) which might be expected to contain the invention?
Essential
**Question 3 -** What is the scope of the claim?
Moderate

**PORTFOLIO NEED** View PPM Needs List
What are the portfolio needs in the area of your invention?
Listed in PPM Needs

**EXPLOITATION & ENFORCEMENT**
**Question 1 -** How easily can the use of the invention by a competitor be detected?
With work
**Question 2 -** How easily can the use of the invention be avoided by a competitor?
With work

**BUSINESS VALUE**
**Question 1 -** What percentage of the companies producing products in the field of this invention might use this invention?
Broadly cloned
**Question 2 -** What is the value of this patent to current or anticipated Alliance Activity between IBM and other companies?
Some value
**Question 3 -** What is the value of this patent to current or anticipated Technology Transfer Activity between IBM and other companies?
Some value
**Question 4 -** Does it result in prestige to IBM?
External

**Post Disclosure Text & Drawings**
Enter any additional information relating to this disclosure below:

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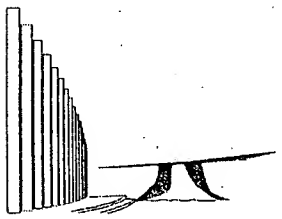
# Wafer Level Underfill Project

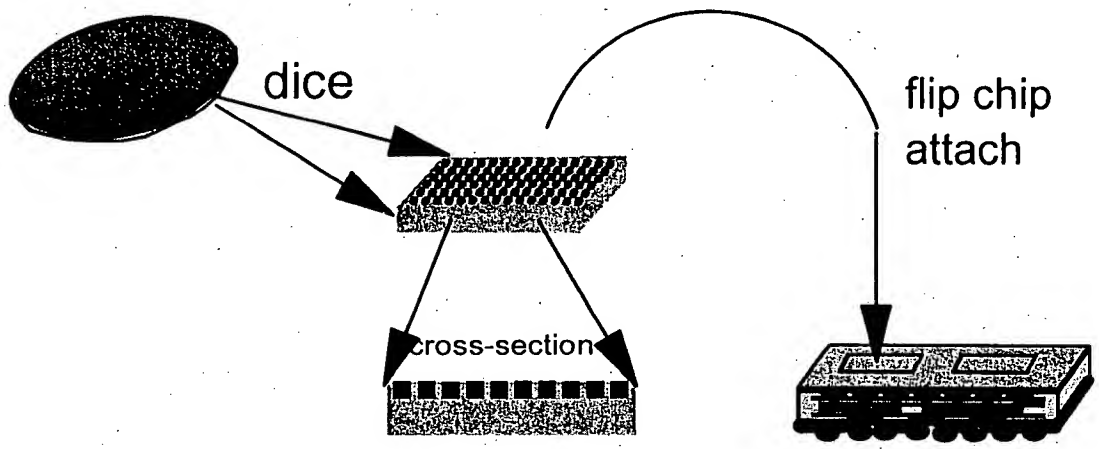
IBM Research
National Starch and Chemical Corp.
NIST-ATP



IBM

T.J. Watson Research Center

# Wafer-level Underfill




- Concept: applying interconnect and underfill at wafer level
- Reduce chip assembly to one step
- Eliminate two manufacturing bottlenecks:
  - underfill flow
  - underfill post-cure
- Lead-free
- Reworkable



IBM

# Industry Trends and Assumptions

- Strong growth in flip chip market
- Strong semiconductor growth
- Lowest cost solution consistent with electrical performance and form factor requirements will be rewarded in marketplace
- Lead-free interconnects will be required
- Low cost packaging solutions will increase marketshare for IBM semiconductors
- BAT is a major part of packaging cost



IBM

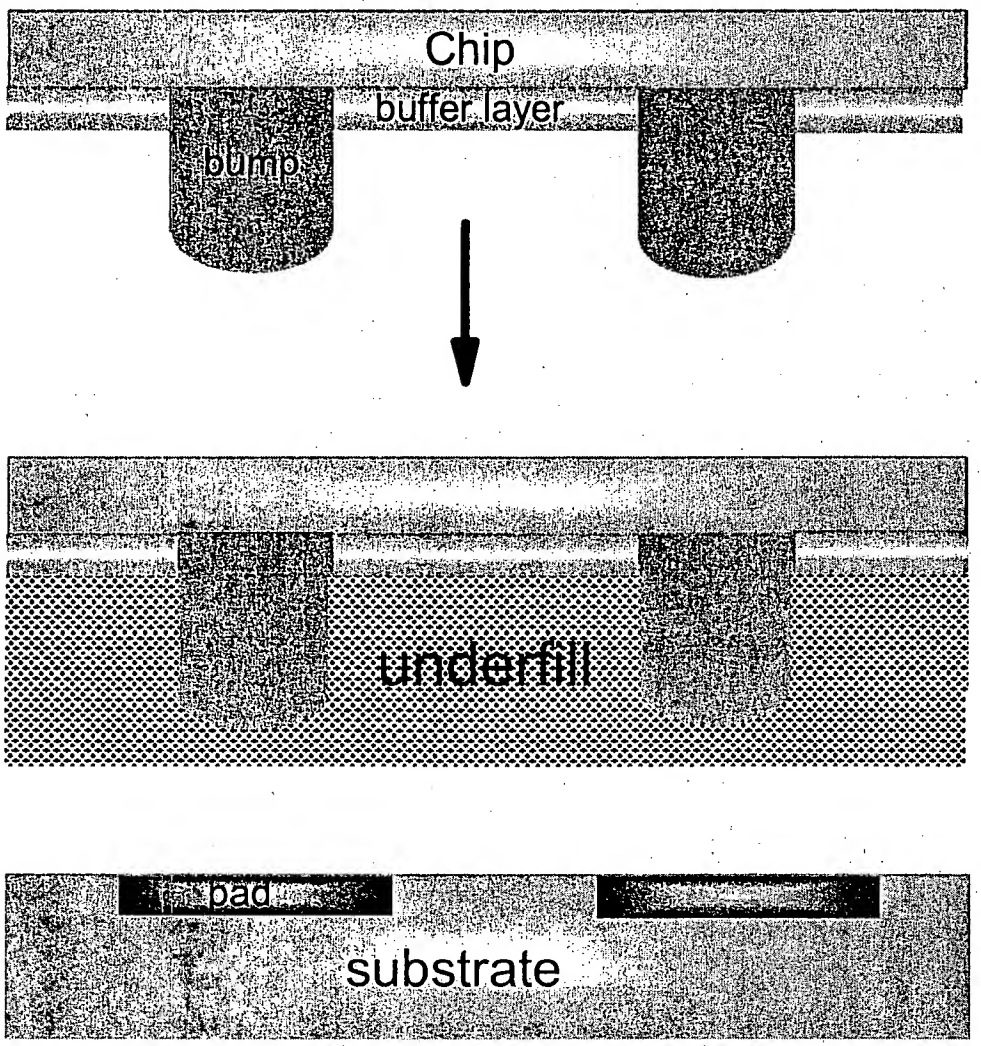
# Wafer-level Underfill - IBM Milestones

- Develop WLUF process schemes;
- Select underfill deposition process on bumped wafers with uniform coating of correct thickness;
- Select approach that has highest likelihood of success, is cheapest, and easiest to integrate in current process flow;
- Ensure compatibility of wafer-level underfill material and process with Pb-free wafer bumping processes;
- Evaluate feasibility of potential reworkable underfill materials;
- Adapt, as necessary, existing wafer dicing process parameters and correlate them to dicing-induced underfill defects.



IBM

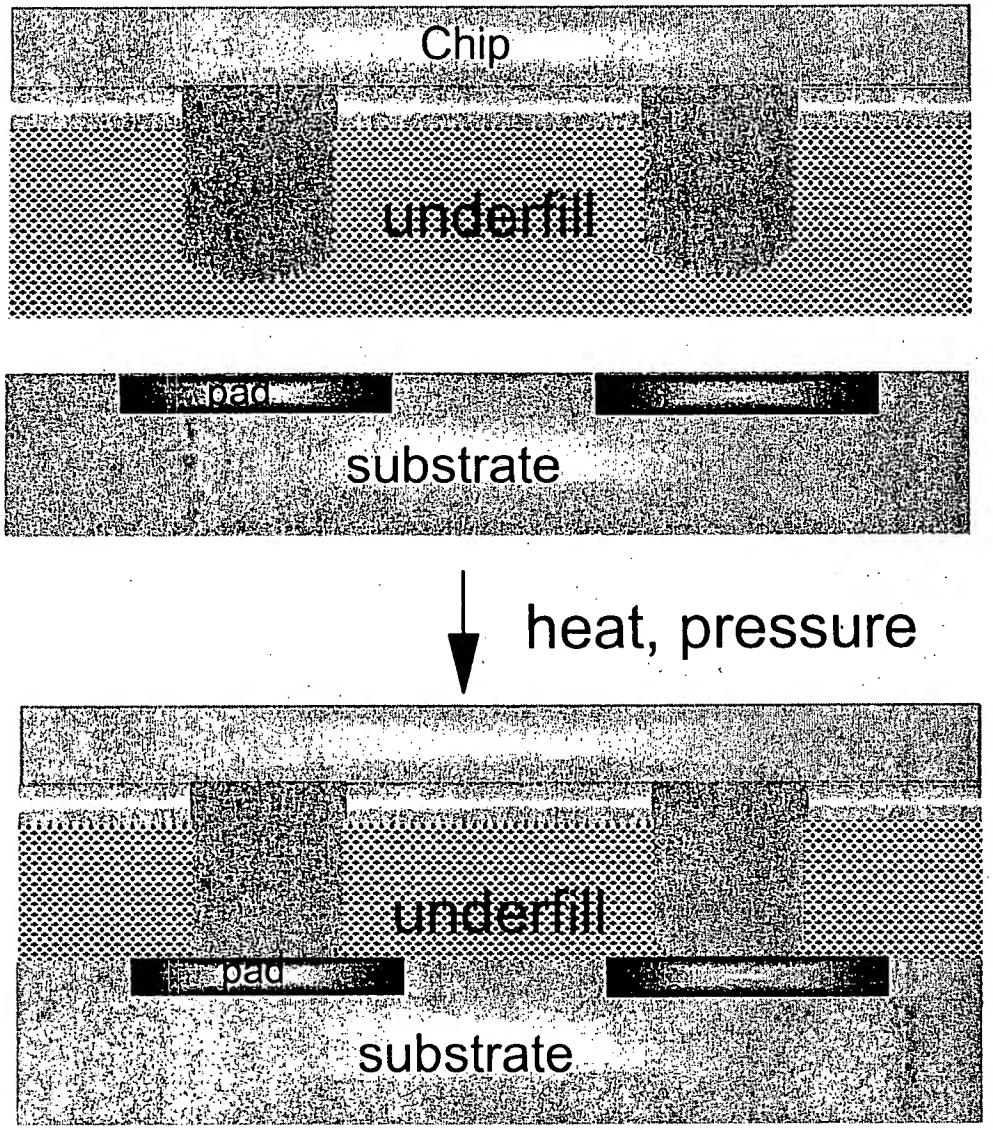
# WLUF Project: Bumps First




WLUF apply processes:

- spin coating
- screening
- curtain coating
- etc.

# WLUF Project Bumps First




Hierarchy for joining:

underfill softens

then

bump softens

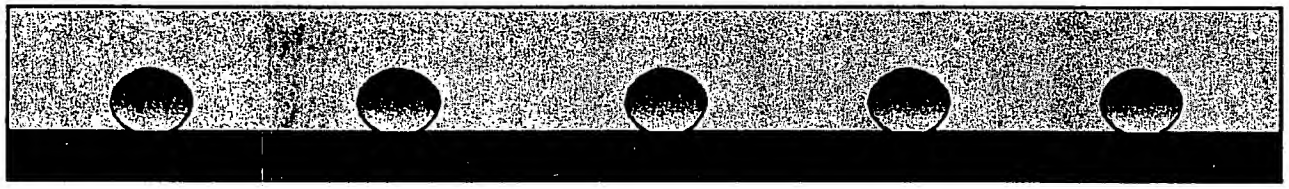
# Wafer-level Underfill - IBM Milestones

- Develop WLUF process schemes;
- Select underfill deposition process on bumped wafers with uniform coating of correct thickness;
- Select approach that has highest likelihood of success, is cheapest, and easiest to integrate in current process flow;
- Ensure compatibility of wafer-level underfill material and process with Pb-free wafer bumping processes;
- Evaluate feasibility of potential reworkable underfill materials;
- Adapt, as necessary, existing wafer dicing process parameters and correlate them to dicing-induced underfill defects.



IBM

# Film Thicknesses



Too much

Too little

Just right



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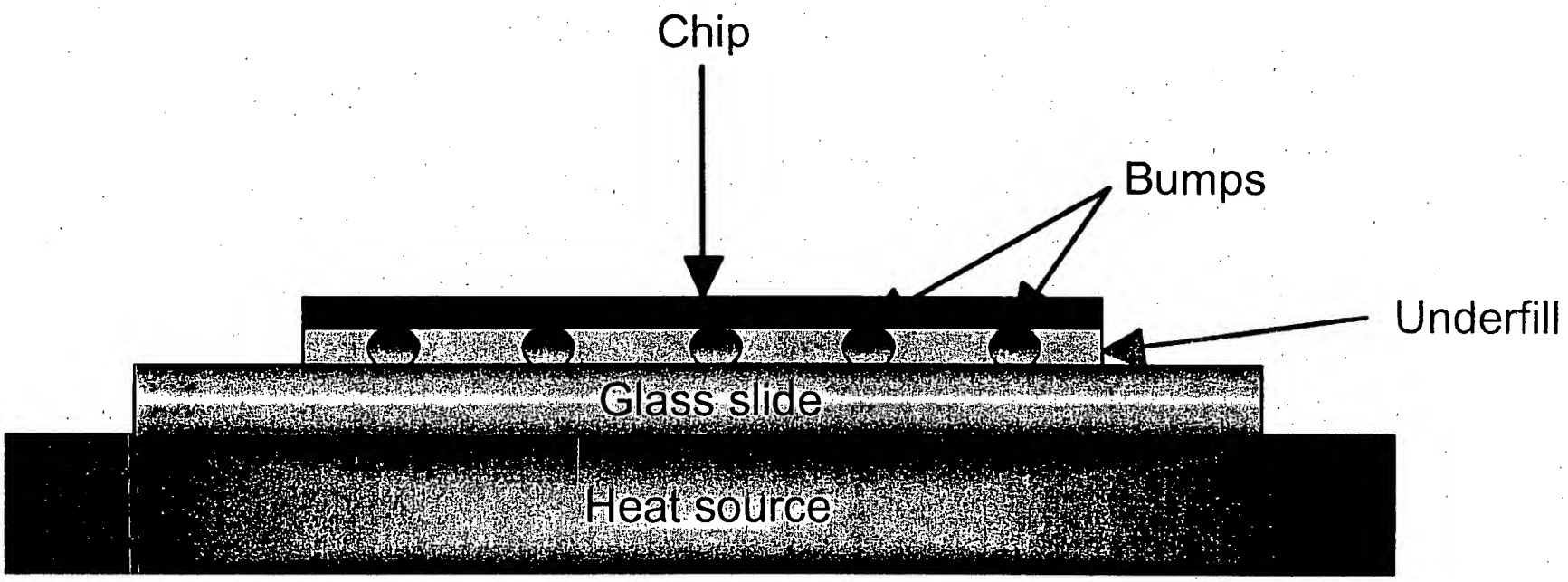
# Test Structure



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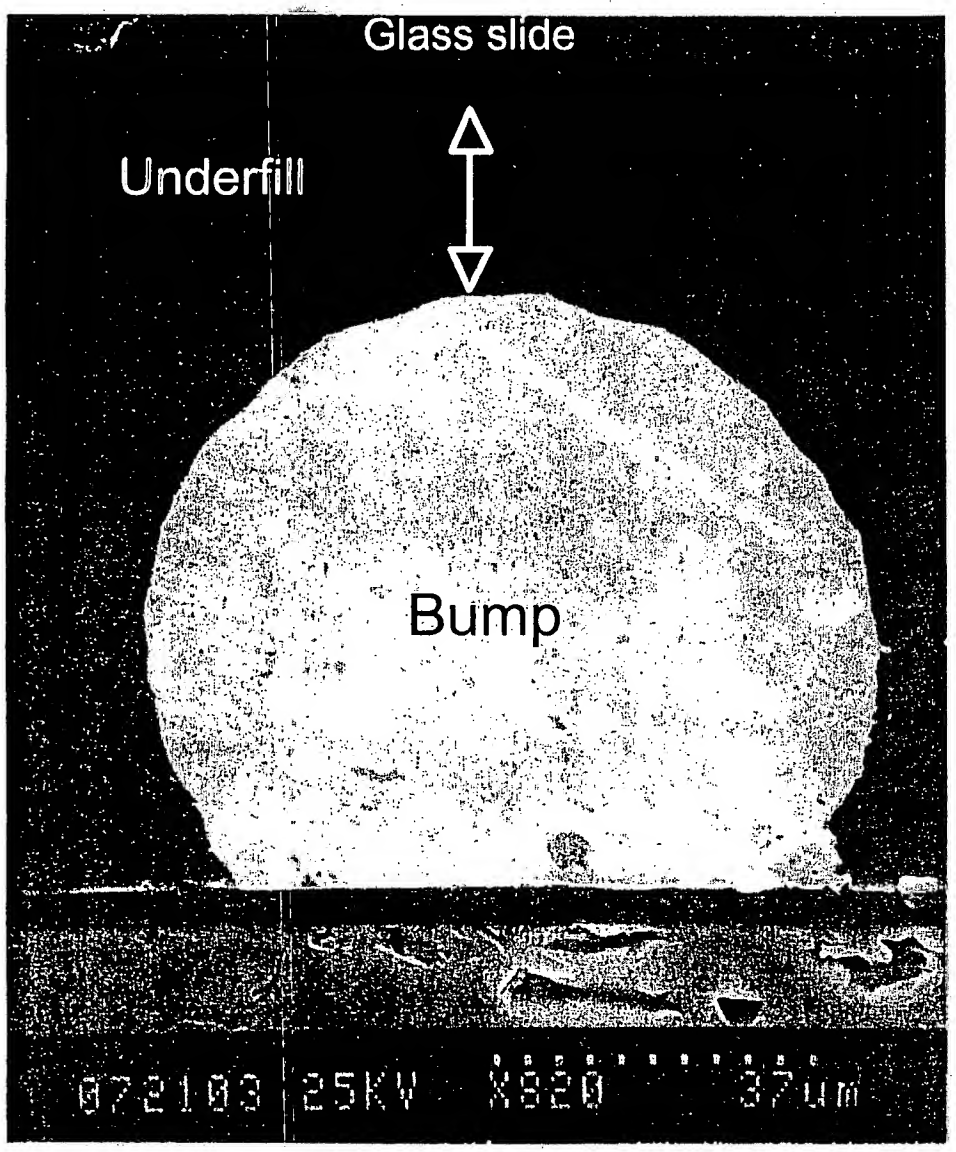
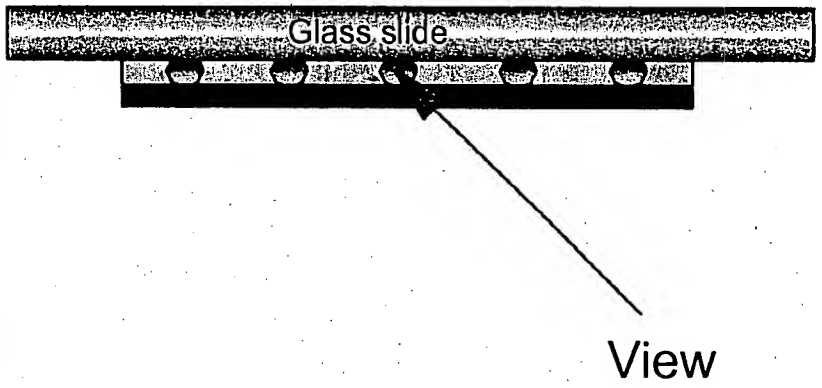



# National Starch 19A
# 220 C Hot Plate
# 3 minutes Dwell time

## No Pressure



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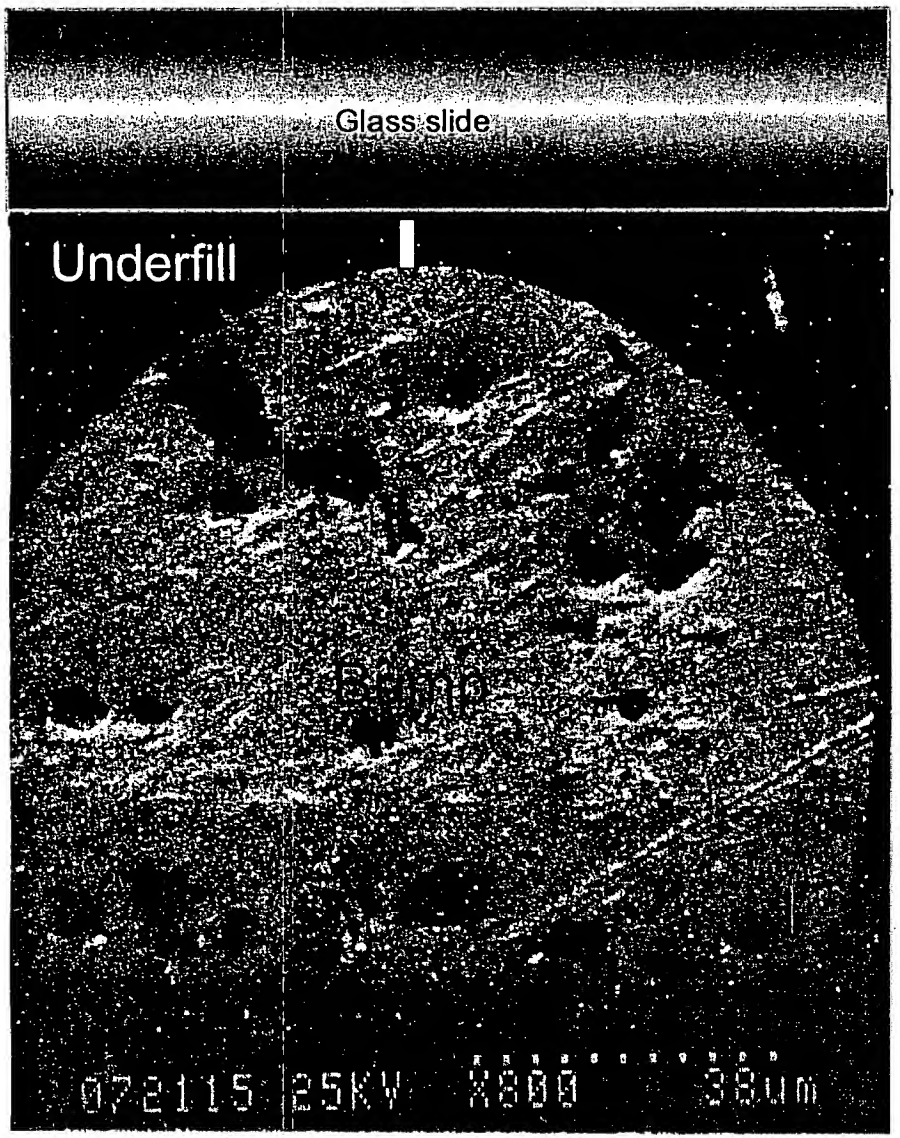
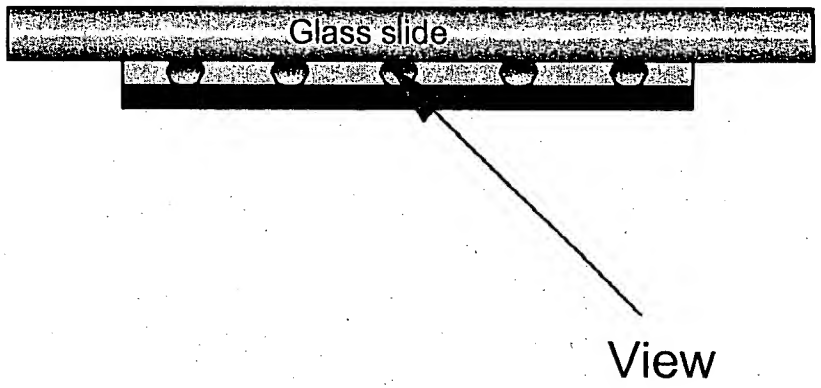



# National Starch 19A
# 200 °C 3 minutes

## With Pressure



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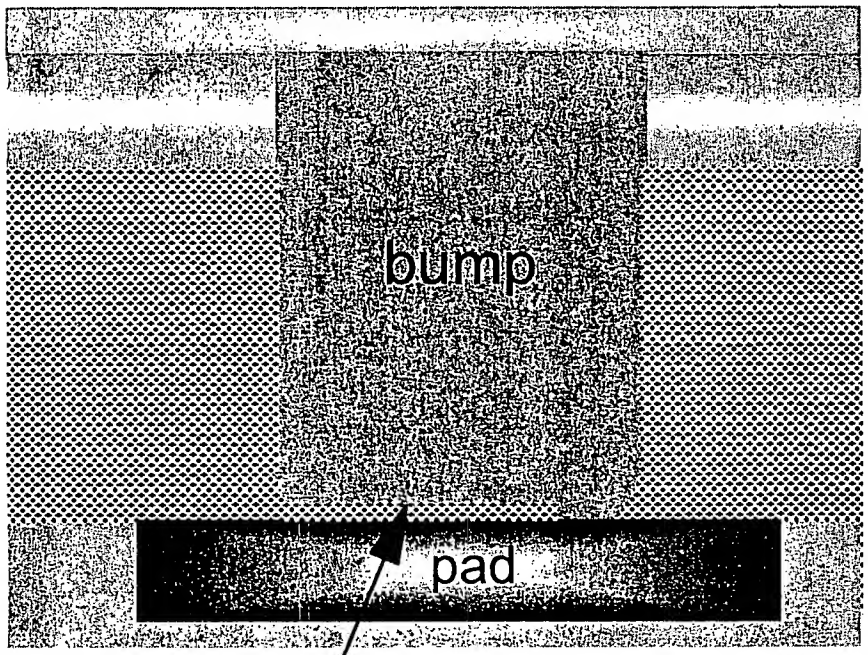
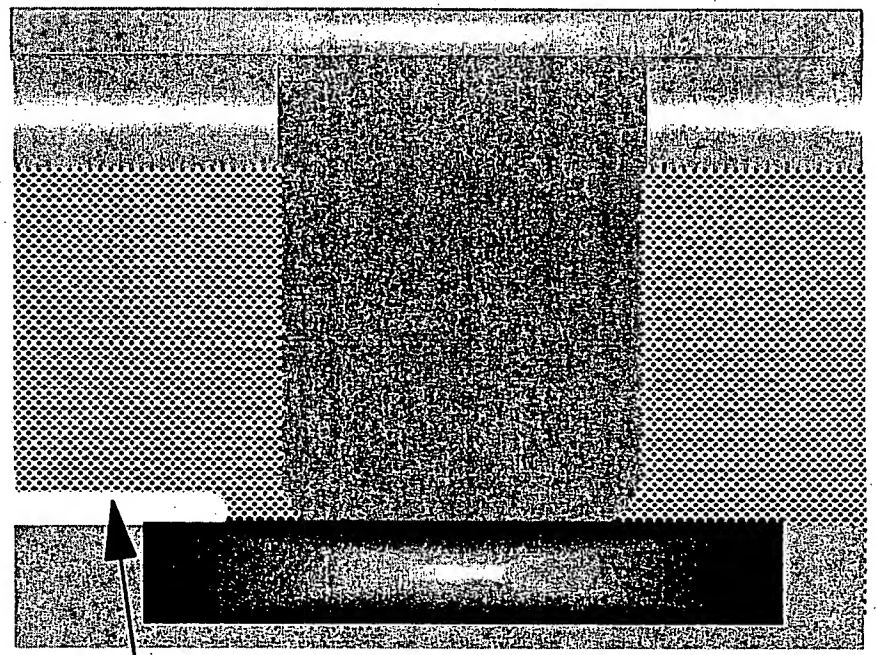
# WLUF Project Bumps First Issues



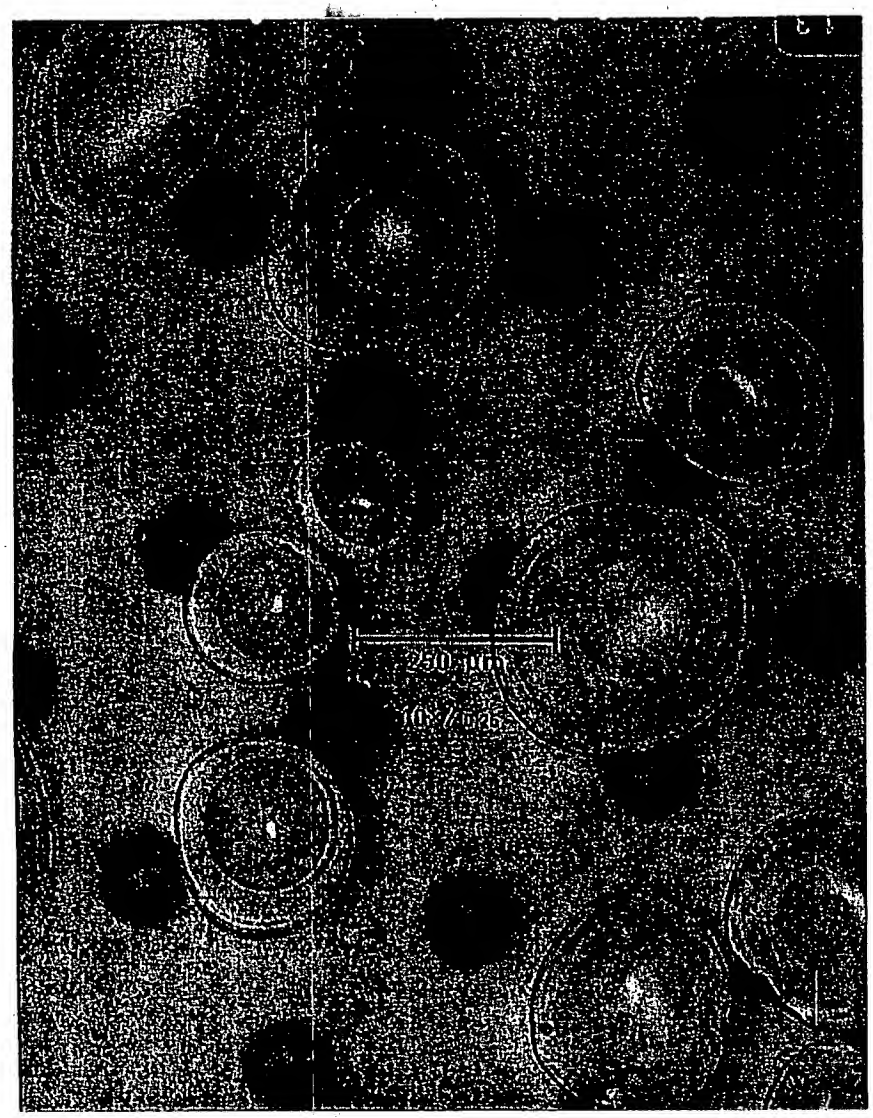

incomplete bump/pad contact



trapped air

fillet formation

# Cure/Bond Study - Polyimide Adhesive



B-staged at 90C and 120C

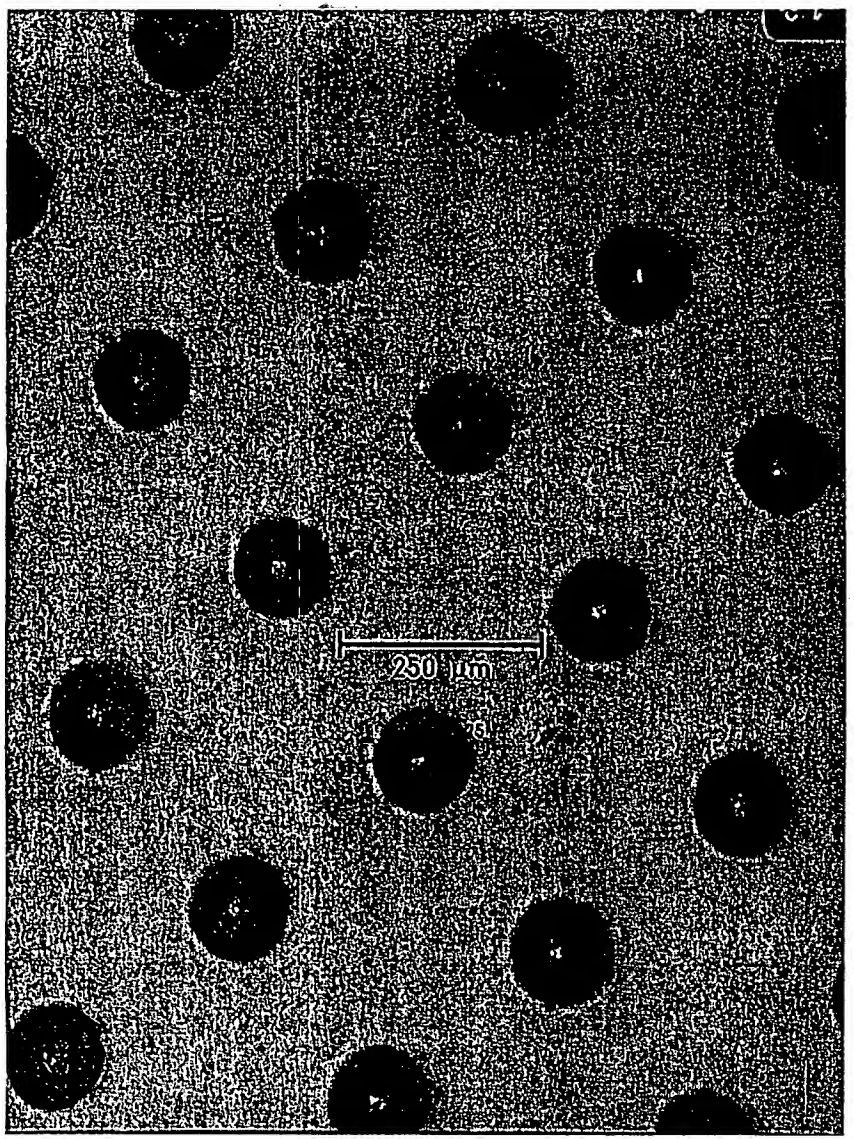
Bonded to glass at 220C using pressure

Major voids / bubbles



IBM

# Cure/Bond Study - Polyimide Adhesive



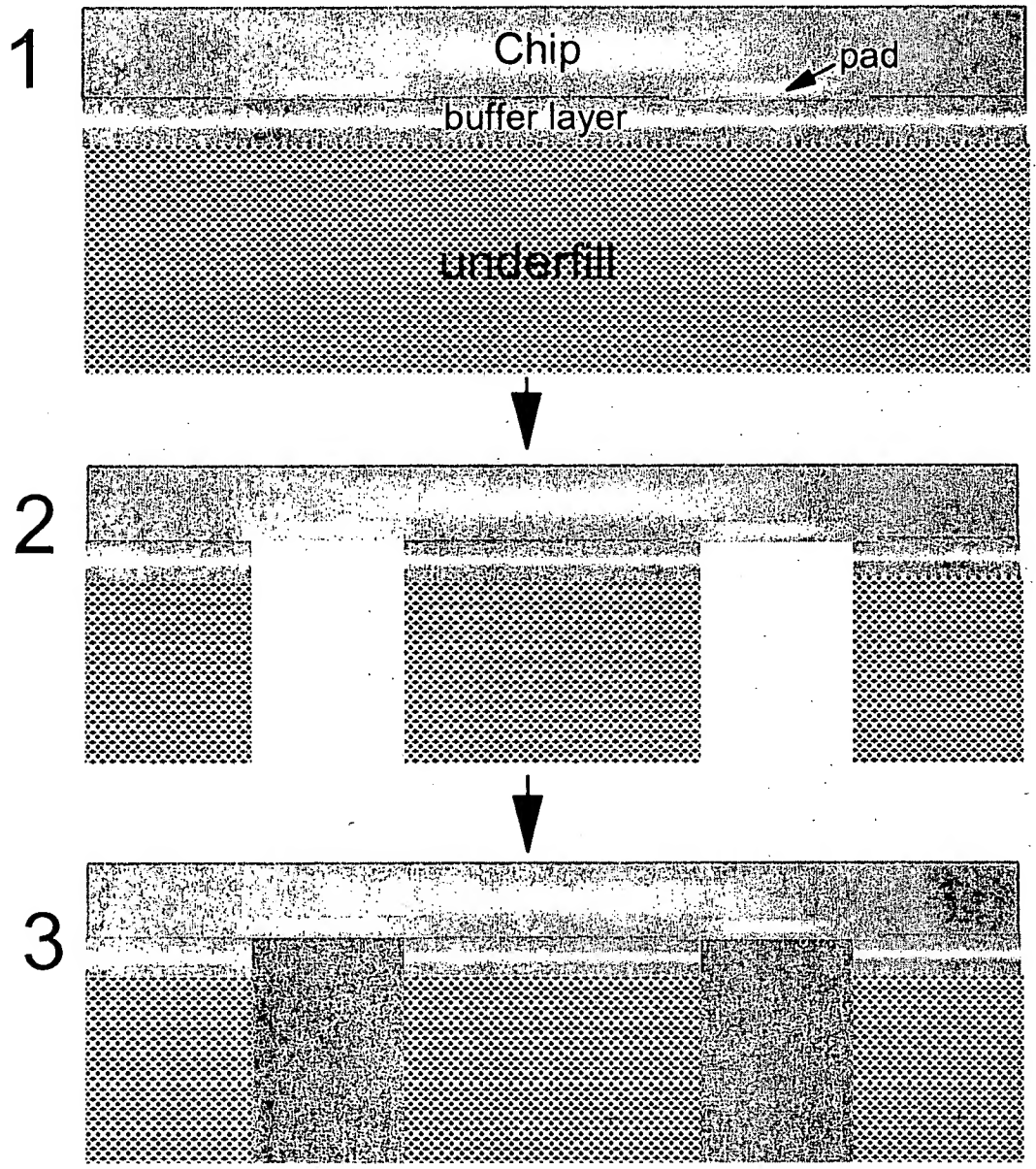

B-staged at 90C, 100C and 120C

Bonded to glass at 220C using pressure

No voids, good wetting of underfill

IBM

# WLUF Project Bumps Second Conductive Adhesive



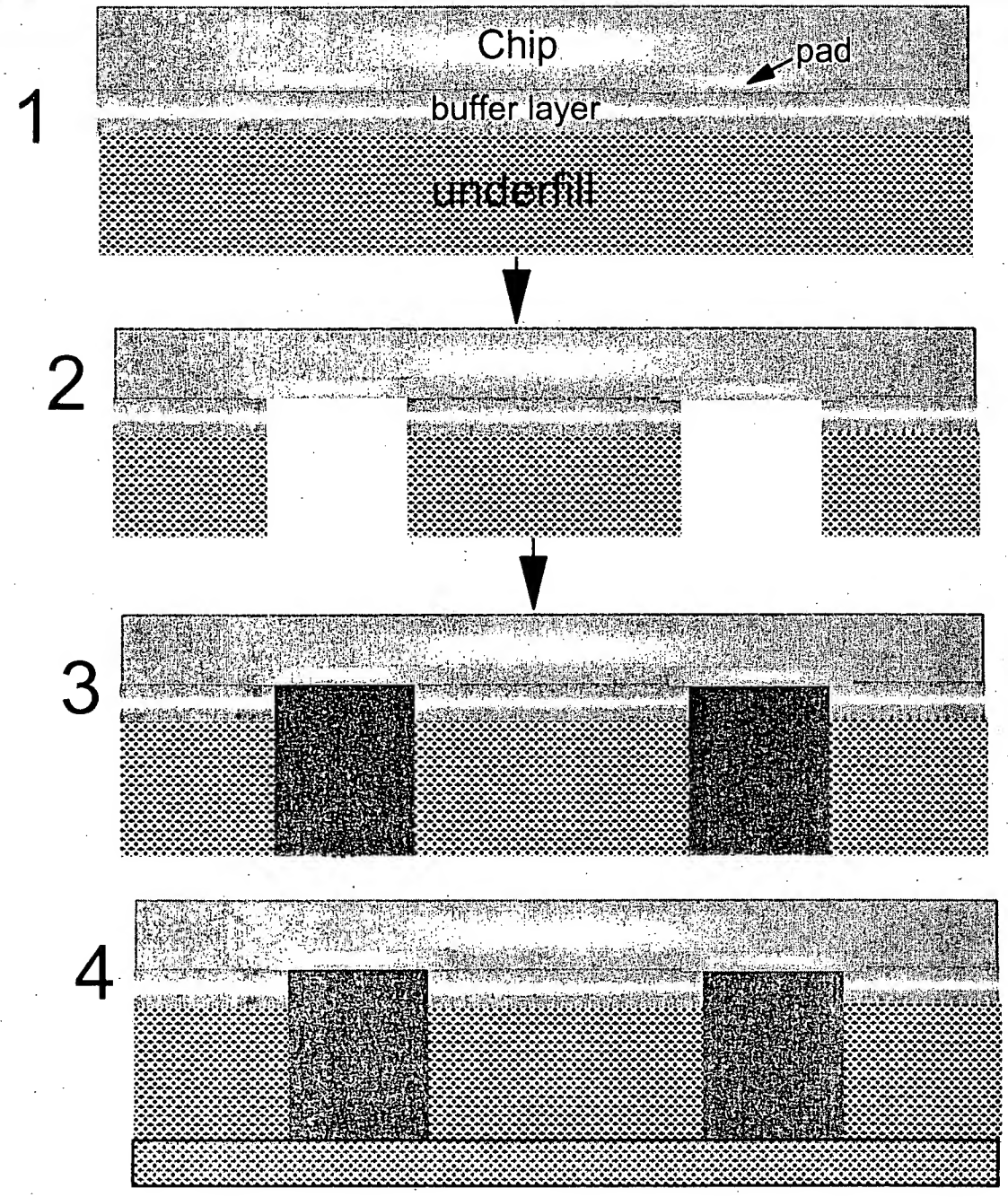

WLUF patterning processes:

- laser ablation
- RIE etching
- wet etching
- photodefinable underfill

Bump fill with conductive adhesive

Join with underfill softening before conductive adhesive

# WLUF Project Bumps Second Bi-layer/Solder



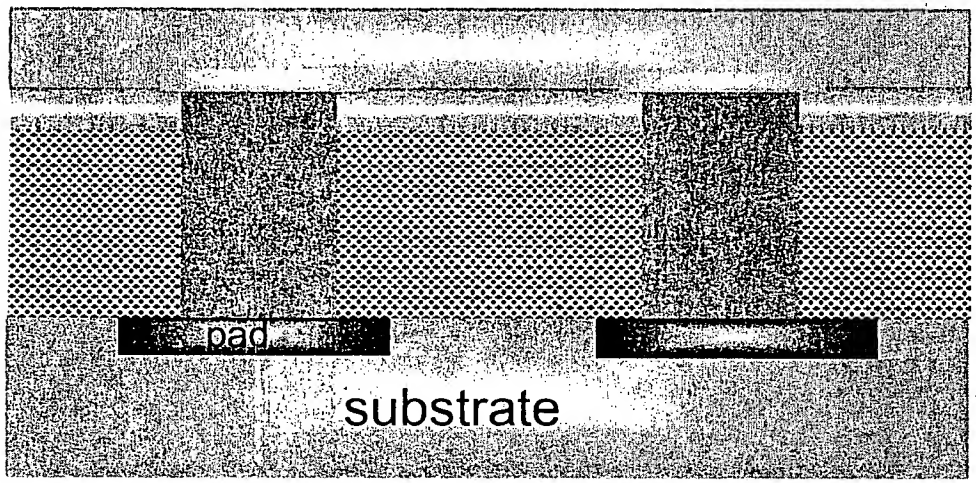

WLUF patterning

Bump fill with molten solder (IMS)

Apply fluxing adhesive

Join through soft, b-staged adhesive

# WLUF Project Bumps Second




issues are essentially same as for bump first



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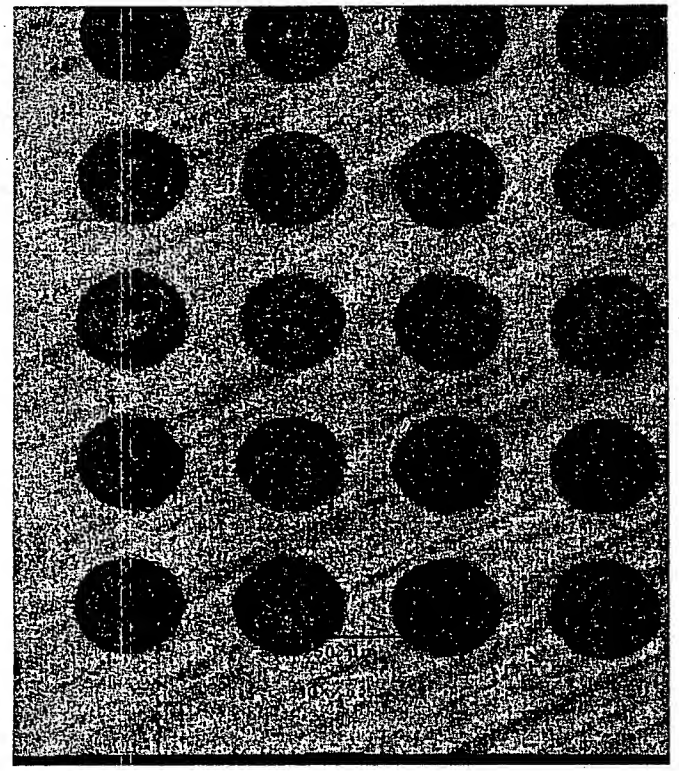
# Bumps Second - Hole Fill and Bonding



Patterned polyimide adhesive

Conductive paste in vias

Bonded to glass at 220C (w/pressure)

Good adhesion to glass

Conductive paste flush with glass



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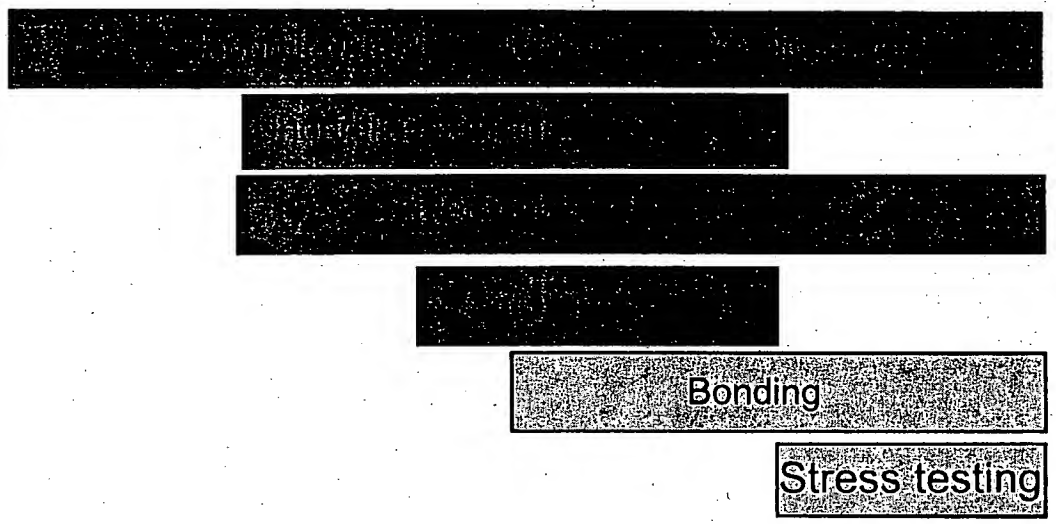
# Development Schedule




- ► demonstrate feasibility on test vehicles
- ► workable flip chip attach and reliable flip chip interconnects

- NIST-ATP Support jointly with National Starch:
  - ► 3 Research H/C + post-doc
  - ► National Starch & Chemical team
  - ► Georgia Tech

Two fundamentally different approaches:

- Bumps first: more packaging oriented (receive bumped wafers)
- Bumps second: more wafer fab oriented (change bumping process flow)

Demonstrate proof of concept for each approach and prioritize by using decision flow charts

Gather info on pros and cons

Choose approach that has highest likelihood of success, is cheapest, easiest to integrate into current process flow.

Work with Endicott and E.Fishkill to guide process development

# Wafer Level Underfill Decision Chart

| Item | Choices | Status | Target date for decision | Lead person |
|---|---|---|---|---|
| Dispense Process | Spinning, Screening, Laminating | Spinning chosen | | |
| Bumping | Bumps first or Bumps second | Tentatively Bumps 2nd | | |
| Bumps | Pb-free solder or cond. adh. | In play | | |
| Underfill | NS&C, other, reworkable, non-reworkable | In play | | |
| Underfill post-dispense process | Laser ablation, Photoresist & etch, or photo-imageable | In play | | |
| Underfill structural aspect | Single layer or bilayer | Patent disclosure pending | | |
| Package topography | Planar or protruding bumps | In play | | |